Lagrangian Turbulence and Transport in Semi-Enclosed Basins and Coastal Regions

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LONG TERM GOALS

The long-term goal of this proposal is the development and application of new methods of investigation for the use of Lagrangian data. Special attention is given to the development of new techniques for the assimilation of Lagrangian data in Eulerian numerical models. Another objective is to improve previous results on statistical prediction of particle transport using data analysis and stochastic models.

OBJECTIVES

1) To develop and apply new techniques for assimilation of Lagrangian data in ocean general circulation models (OGCMs).
2) To investigate statistical prediction of particle transport using data analysis and stochastic models.

APPROACH

The work involves a combination of analytical, numerical and data processing techniques. The key individuals participating in this work are: Anne Molcard (RSMAS/MPO) involved in the application of the assimilation methods; Leonid Piterbarg (USC) in the mathematical formulation of the method; Milena Veneziani (RSMAS/MPO) in the analysis of Lagrangian data; Mike Chin (RSMAS/MPO) in the comparison of the assimilation methods.

WORK COMPLETED

1) Application of the assimilation method to a reduced gravity MICOM model, in order to solve the multiple variable problem. The results are in press in J. Geophys. Res.

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14. ABSTRACT
The long-term goal of this proposal is the development and application of new methods of investigation for the use of Lagrangian data. Special attention is given to the development of new techniques for the assimilation of Lagrangian data in Eulerian numerical models. Another objective is to improve previous results on statistical prediction of particle transport using data analysis and stochastic models.

15. SUBJECT TERMS

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2) Application of the assimilation method to a 3-layer MICOM model, in order to solve the multiple variable and multiple layer problem. Results are presented in a paper in preparation.
3) Application of stochastic models to the analysis of 2 Lagrangian data sets, in the Adriatic and in the N.W. Atlantic. Results are presented in 2 papers submitted to J. Geophys. Res. And to J. Phys. Oceanogr. respectively.

RESULTS

The main results, obtained in collaboration with other scientists, can be summarized as follows.

1) Extension of the applicability of the Lagrangian assimilation method developed by Molcard et al. [2003] in a QG model to a reduced gravity MICOM model.

The Lagrangian assimilation technique is implemented in MICOM, which is a primitive equation layered ocean model (Bleck and Boudra, 1981). The reduced-gravity, midlatitude double-gyre ocean model configuration allows for a highly nonlinear interaction between dynamically different ocean flow regimes, while being far simpler than carrying out realistic ocean simulations. The main obstacle to the implementation of the Lagrangian assimilation in a PE model with respect to a quasi-geostrophic model, is that a single prognostic variable (vorticity) is integrated in the quasi-geostrophic formalism, whereas primitive equation models typically integrate three prognostic variables (horizontal velocity components and layer thickness or pressure).

The dynamical compatibility between corrected model-velocity and layer-thickness fields is accomplished using a simple and computationally efficient formulation based on geostrophic balance and mass conservation. The basic assumption is that we assume that the dynamical relation between model variables is satisfied also by the respective corrections.

A set of experiments is conducted by including or excluding the layer thickness correction term, and Fig.1 illustrates the validity of the simple dynamical balancing technique.

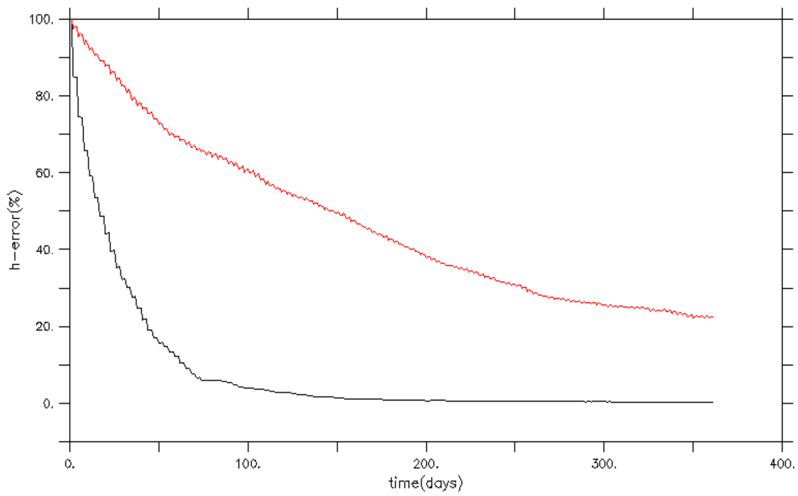

Fig1: Layer thickness error h_{error} (in %) versus time (in days) with (black curve) and without (red curve) the correction of layer thickness in the case of 121 drifters and a sampling period Δt of 3 days. Results show that the error significantly reduces when thickness is corrected.

When only the velocity is corrected the response of the ocean model to assimilation is found to slow down drastically, which indicates that the correction of model velocity must be accompanied by an appropriate correction of layer thickness.

Furthermore the general performance of this assimilation method, which is based on optimal interpolation and incorporates a number of simplifications in its present implementation, has been compared to that of an approximated implementation (ROIF) of Kalman filter (Chin et al., 2002).

This comparison has shown the improvement in performance due to Lagrangian technique.

2) Extension of the applicability of the Lagrangian assimilation method developed by Molcard et al. [2003] in a 3-layer MICOM model.

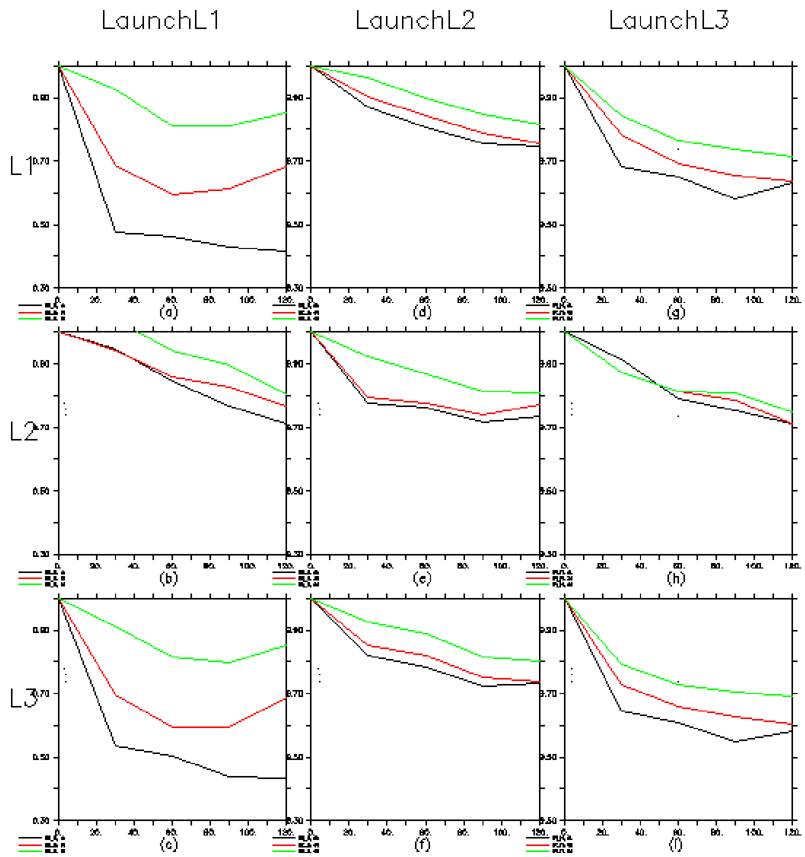

Fig2: Relative velocity error versus time (in days) in each layer (first line layer 1;second line layer 2;third line layer3) for the three launchings (first column launch in layer1; second column launch in layer 2; third column launch in layer 3). The three lines in each plot correspond to different time sampling period (1200s (black), 3d (red), 6d (green)). Results show that the error significantly reduces in time.

A general methodology has been developed for assimilation of LaGrange data in a multi-layer primitive equation model, assuming that LaGrange data are launched in one layer only. This can be resumed in three major points.

i) From two successive float positions, the LaGrange velocities are computed and they are compared with the LaGrange model velocities computed from synthetic drifters released and adverted in the model. This is done by a simple OI-based assimilation method that minimizes the final distance between measured and simulated position (Mol card et al, 2003a).

ii) In the remaining layers where no floats are measured, the velocity correction is computed using correlation factors between layers observed empirically from model simulations. For each individual column of model grid points we define the vertical regression coefficients that represent the rate of change of one variable (the velocity correction in a layer) as a function of changes in the other (the velocity correction in the layer where we have drifter observations).

iii) Some simple assumptions (e.g. geostrophy) are made in order to analytically solve the dynamical relation between model variables that we assume to be satisfied also by the respective corrections (Özgökmen et al, 2003).

The methodology has been tested on a 3-layer MICOM model and has shown its success in improving the forecast when Lagrangian data are assimilated (Molcard et al. 2003b).
Three experiments are conducted in order to analyze the efficiency of the assimilation depending on the depth at which the Lagrangian data are travelling: launching in layer 1 (0-400 m), launching in layer 2(400-700), launching in layer 3 (700-4000).

The efficiency of the assimilation is measured by a quantitative metric, the relative error, defined as the ratio between the rms velocity difference between the true ocean state and the simulation with assimilation and the rms velocity difference between the true ocean state and the simulation without assimilation. If the assimilation is successful, the relative error should be smaller than 1, and as long as it is effective, the slope should be negative.

The time evolution of the relative errors for the three launching experiments is plotted in Fig.2.
In all cases the assimilation improves the forecast as the slopes are always negative and a significant error reduction is achieved at the end of the integration.

3) Application of stochastic models for statistical prediction of Lagrangian particles in presence of coherent structures

The historical data set of 700 m floats (e.g. Richardson 1993) has been analyzed in various regions of the N.W. Atlantic with the goal of exploring the use of stochastic models to statistically predict Lagrangian velocities and transport. In the Gulf Stream recirculation and extension, autocovariances exhibit significant oscillatory patterns, often indicative of super-diffusive behaviors, as shown in Fig.3. Our main result is that these properties are due to the superposition of two different regimes associated with "looping" trajectories, imbedded in coherent structures such as vortices and rings, and non looping trajectories, characteristics of the background turbulent flow (Fig.3). Both regimes can be described using a simple first-order Lagrangian stochastic model with spin parameter (Reynolds, 2002). The spin couples the zonal and meridional velocities, reproducing the effects of rotating coherent structures. It is considered as a random parameter whose probability distribution is approximately bi-modal, reflecting the distribution of loopers (finite spin) and non-loopers (zero spin). This simple model is found to be very effective in reproducing the statistical properties of the data (Fig.3).

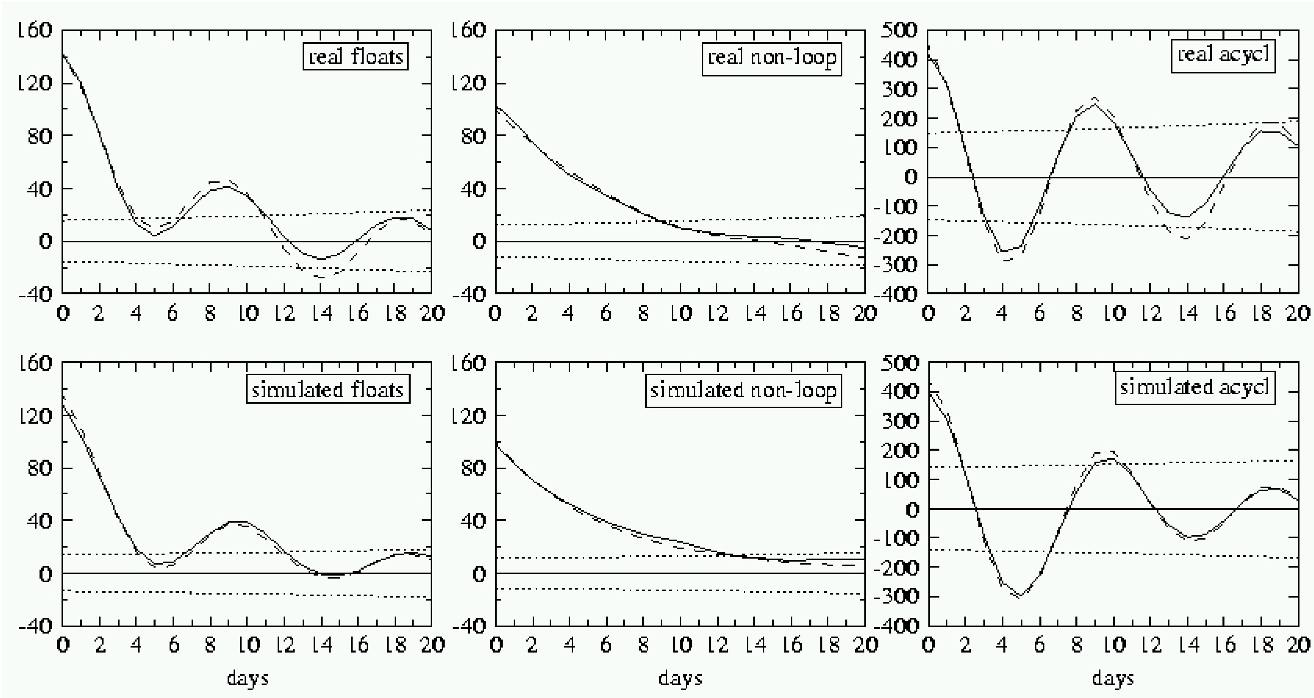

Figure 3: Velocity autocovariance functions computed in the Gulf Stream recirculation region. Upper three panel show results from float data: overall data set (left), non-looping floats (middle), and looping floats (right). Lower three panels show results from stochastic models: simulated total trajectories (left), simulated non-loopers (middle), and simulated looper (right). Direct comparisons can be made between the real and the modeled statistics by comparing the lower with the upper panels. Results show the excellent agreement.

IMPACT/APPLICATIONS

The results have the potential to impact current studies for a number of problems. From the methodological point of view, the results indicate the potential of using Lagrangian data for assimilation in GCM's. Also, the results show that simple stochastic models of first order can be used to effectively describe Lagrangian statistics even in presence of coherent structures.

TRANSITIONS

Lagrangian data assimilation methods are planned to be used in the framework of realistic and operational models, such as the North Atlantic and Mediterranean models (MFSTEP, EEC project). Stochastic methods for the interpretation and the statistical prediction of Lagrangian data are carried out in collaboration with P.Poulain and A. Provenzale (CNR, Italy).

RELATED PROJECTS

Related projects are carried out with other investigators funded by ONR, NSF, and the European Community. Of particular importance is the collaboration with L. Piterbarg, which has been a main cornerstone of the performed work:

"Statistical and stochastic problems in Ocean Modeling and Prediction. Stage II." ONR, L. Piterbarg

Other related projects include:

"Predictability of particle trajectories in the ocean", ONR, T.M. Özgökmen, A. Griffa, A. Mariano
"Mediterranean Forecasting System", EEC, N. Pinardi
"Turbulence and mixing", EEC, A. Provenzale

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